The National TCAD Framework: An Information Power Grid Application

Bryan A. Biegel

Numerical Aerospace Simulation Division

NASA Ames Research Center

Seminar at:

Center for Integrated Systems

Stanford University

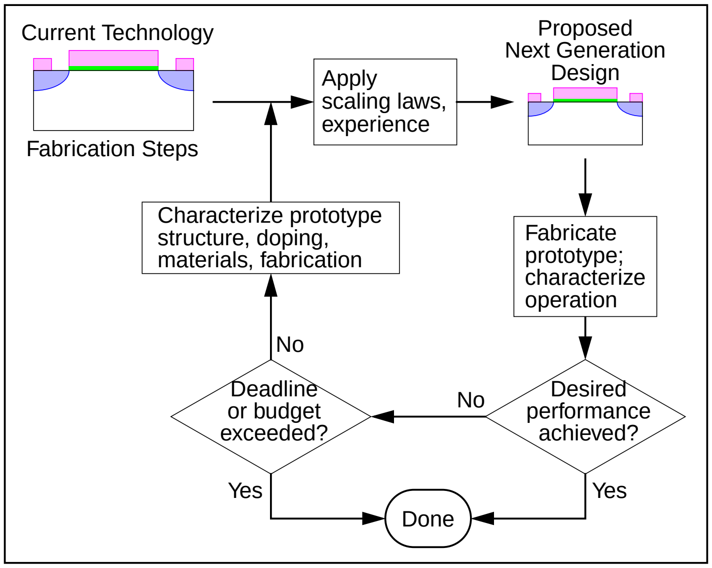
October 8, 1997

The National TCAD Framework: An Information Power Grid Application

Outline

- Background & Motivation
- The National TCAD Framework
- The Information Power Grid
- Conclusions

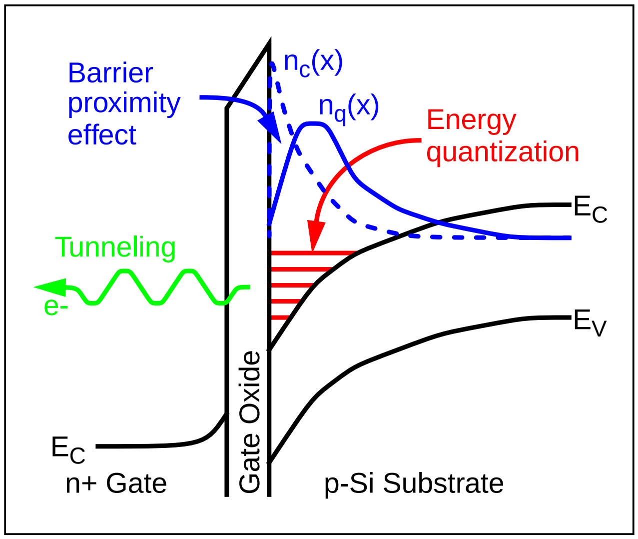
Traditional Approach to Semiconductor Technology Advancement



Problems with Scaling Laws and Experimental Iteration as Devices Shrink

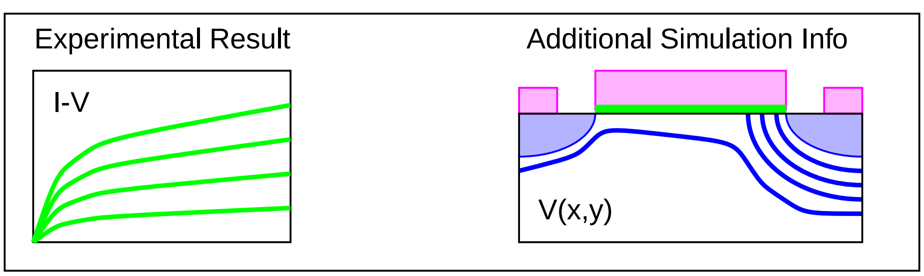
- Experimental iteration increasingly expensive and slow
- Scaling laws are failing:
  - Fabrication, material changes
  - Devices structure changes
  - Small-geometry/high-field effects:
    - hot electron transport, punch-through, avalanche multiplication, drain-induced barrier lowering, oxide and junction breakdown, leakage currents
  - Microwave effects
  - Quantum effects:
    - gate oxide tunneling, inversion layer quantization, quantum transport, and transconductance degradation
- Scaling laws do not prepare us for transition to quantum devices

Quantum Effects in an n-MOSFET



Potential Advantages of TCAD

- More general cases than scaling
- Much less expensive than experiment
- View of internal processes
- Investigation of individual physical effects
- Ultimate control of time, temperature, position, environment



Why are these just POTENTIAL advantages?

TCAD Tools: What Industry “Needs”

Existing capabilities:

- 3-D process and device simulation
- Intuitive graphical user interface (GUI)
- High-quality graphical output (1-D, 2-D, 3-D, transient)
- Optimized for large computations
- Coupling of simulation tools

Non-existing functionality:

- Arbitrary process steps, device structures, materials, and tests
- Flexible physical model(s)
- Auto selection of numerical methods
- Functional modularity
- Hierarchy of models

General Electronic Device Transport Models

Complexity, Comp. Cost	**Classical**	**Quantum-Corrected**	**Quantum**
Low	Drift-diffusion	Density-gradient	Schrödinger, Transfer matrix
Moderate	Energy balance, Hydrodynamic	Quantum EB, Quantum HD	Density matrix, Wigner function
High	Boltzmann transport equation	Quantum Boltz-mann equation	Green’s functions
Microwave, Optoelectronic	Substitute Maxwell’s equations for Poisson equation		

Challenges for TCAD Development

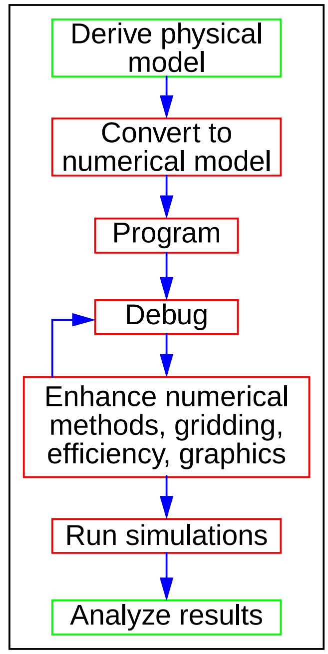
1) Developing TCAD tools is difficult:
- Distance to results analysis is long
- Few coding short-cuts are available
- Little collaboration outside of groups
- No standard for tool interaction

⇒ Never implement sophisticated features industry needs

2) Computation hardware is expensive

⇒ Compromises in model, implementation, execution

3) Inadequate numerical methods



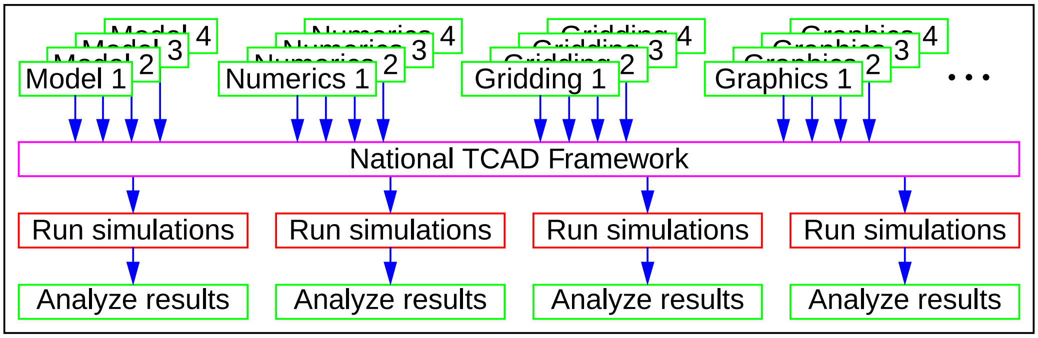
The National TCAD Framework: An Information Power Grid Application

Outline

- Background & Motivation
- **The National TCAD Framework**
- The Information Power Grid
- Conclusions

New TCAD Development Approach: National TCAD Framework (NTF)

Modular TCAD development platform

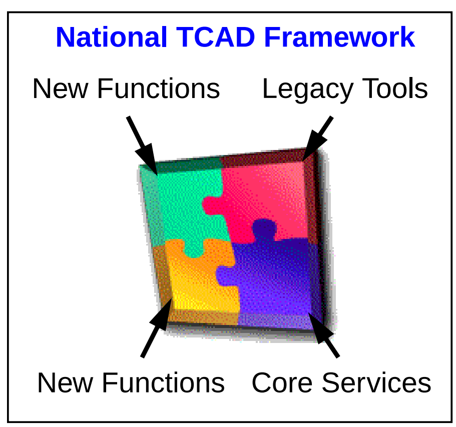


- Enables and encourages collaboration
- Well-defined functional interfaces
- Basic "glue" services

Multiply usefulness of high-level functionality

NTF: Tool Developer Interests

- Plenty of work
- Preserve intellectual property
- Easy to plug into
- Collaboration-at-a-distance
- Modules replaceable at low level
- New facilities for existing tools

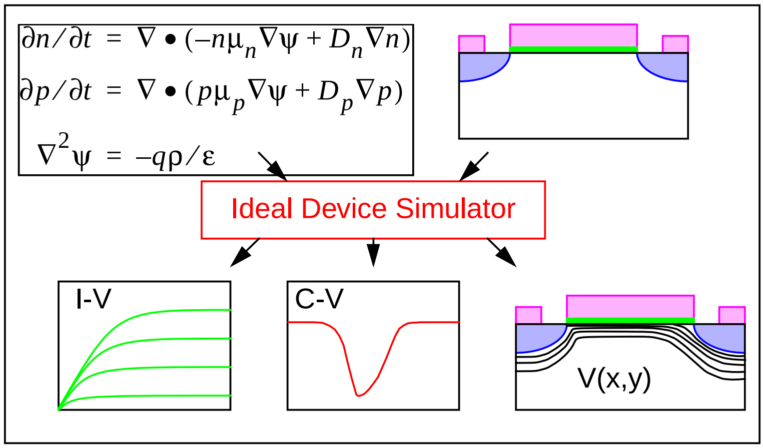


Additional tool vendor interests:

- Protect existing products and customer base
- Add value that people will pay for

NTF: Model Developer Interests

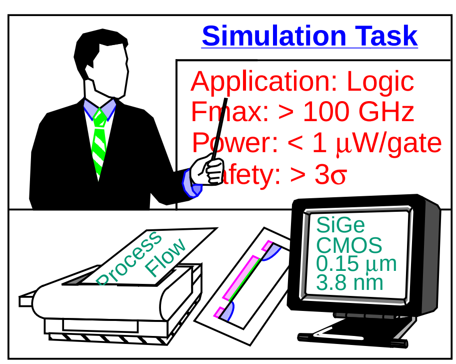
- Model specified as set of PDEs, constraints



- Ideally, model independent of other code
- Practically, collaborate with numerical experts

NTF: User Interests

- Greater functionality
- Better accuracy
- Fewer bugs
- Better ease of use
- More flexibility to modify models, devices, tests
- Bigger problems, more robustness, faster execution
- Platform independence
- Better technical support
- Low initial investment
- High-level functionality using "Artificial intelligence"



NTF: Artificial Intelligence

Expert System Description	Implementation	Rank
Speech recognition	Commercial	3
Natural language and math expression interpretation	Commercial	2
Estimation of device structure or operation	Data mining ES	1
Estimation of computational resources needed	Data mining ES	1
Selection of optimal physical model(s)	Data mining ES	2
Selection of optimal gridding, numerics, solution algorithms	Data mining ES	2
Correction of non-convergence, excess error, device malfunction	Rule-based ES	2
Interactive visualization	Commercial/NASA	1
Gesture recognition	Commercial/NASA	3
Extraction of default and user-defined results/parameters	Rule-based ES	3
Optimization of device according to specified constraints	Rule-based ES	1
Default and user-specified interaction between tools	Rule-based ES	1
Analyze discrepancies between experiment, simulation	Rule-based ES	2
Tune physical model and RSMs using experimental data	Rule-based ES	3
Apply context-sensitive user and default preferences	Rule-based ES	3

Note: ES = expert system; Rank = relative importance

NTF: Related Work

Software Package	GUI	Functional Modularity	Graphical Output	New Physical Models	AI Selection of Numerics	Complex Topologies	Large Computations	Tool Coupling	IPG Compatibility
Mathematica, etc.	Y	N	Y	Y	Y	N	N	N	N
PROPHET	N	Y	poor	Y	N	Y	Y	poor	N
ALAMODE	N	Y	poor	Y	N	Y	Y	N	N
NEMO	Y	Y	Y	N	N	Y	Y	N	N
TMA, Silvaco, etc.	Y	N	Y	N	N	Y	Y	Y	N
NTF	Y	Y	Y	Y	Y	Y	Y	Y	Y

The National TCAD Framework: An Information Power Grid Application

Outline

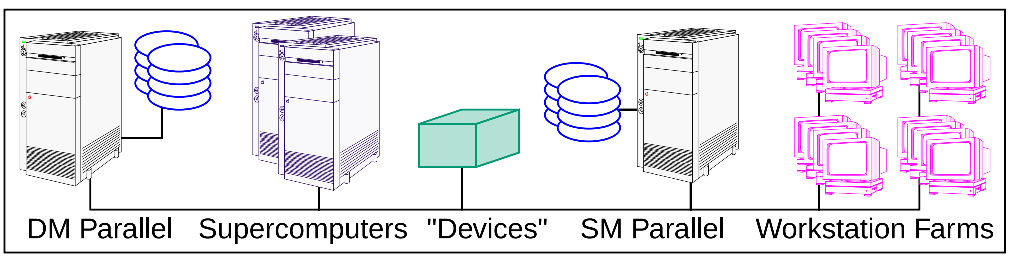
- Background & Motivation
- The National TCAD Framework
- **The Information Power Grid**
- Conclusions

Information Power Grid (IPG): Why?

Observations:

- Many computations of interest (e.g., TCAD) beyond feasibility
- Uncountable CPU cycles are wasted "bit-flips"

IPG goal: To link massive numbers of heterogeneous, distributed compute resources as virtual supercomputer; provide simple access



IPG could largely solve 2nd TCAD challenge: cost of computation

IPG: Benefits/Goals

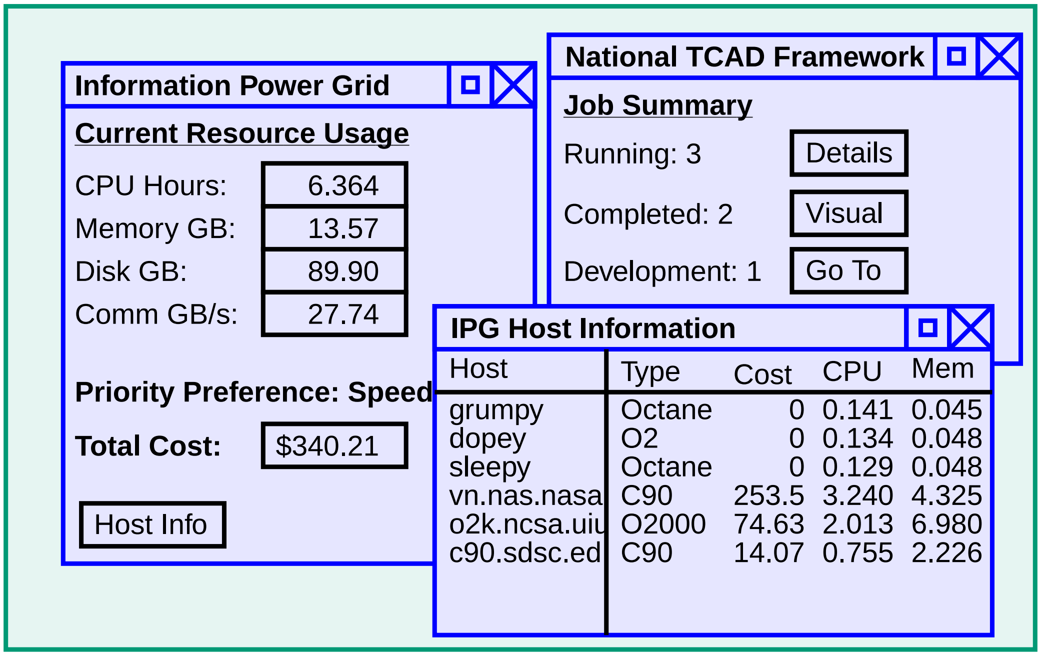
- De-couple computational resources from intellectual resources
- Minimize cost of supercomputing
- Transparent access
- Collaboration-at-a-distance
- Web interface for users, developers

IPG: Implementation Stages

- Web interface to fixed server (network computing)
- Auto-select single host at run-time
- Load-balancing with multiple, pre-compiled hosts
- Dynamic compiling on multiple hosts as determined by:
  - program execution profile
  - user input parameters
  - computational resource database query
  - host availability.

The IPG is just network computing on steroids!

IPG: Interface Scenario



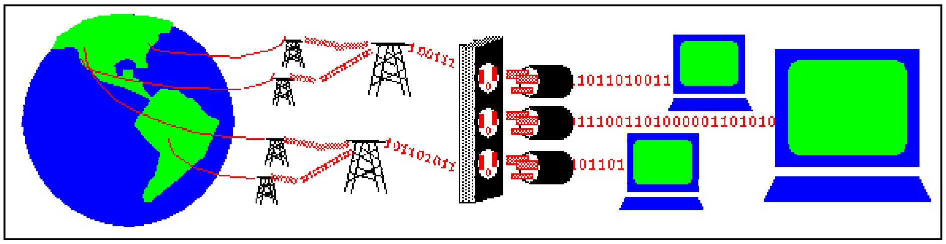
IPG: Requirements

- Buying and selling computational resources, code fees
- Computational resource database server (like a DNS):
  - CPU, memory, disk, bandwidth, cost
- Universal code format (like Java)
- Compilation and execution profile for each application:
  - Best compilation options, libraries required
  - Best execution architecture (scalar, vector, parallel, distributed)
  - Execution resources required versus platform
- IPG operating system (job scheduling, execution profiling, etc.)
- Data and code security

IPG: Analogy to Electric Power Grid

Principal benefits:

- load sharing/balancing
- fault tolerance, minimum loss-of-service
- economies of scale



Principal risks/challenges:

- possible fault domino effect
- reliance on facilities under other's control
- negotiation of agreements
- standards development and compliance policing

IPG: Related Work

IPG Equivalents:

- NPACI (NSF Partnership for Advanced Computational Infrastructure; NCSA, SDSC) http://www.npaci.edu/
- Legion Worldwide Virtual Computer, University of Virginia, http://www.cs.virginia.edu/~legion/
- Globus Metacomputing Environment: http://www.globus.org

Distributed operating systems:

- Inferno (Lucent Technologies) http://plan9.bell-labs.com/inferno/
- Spring (Sun) http://www.sun.com/tech/projects/spring/index.html
- JavaSpaces (JavaSoft) http://chatsubo.javasoft.com/javaspaces/
- Millennium (Microsoft) http://131.107.1.182:80/research/os/Millennium/mgoals.html

The National TCAD Framework: An Information Power Grid Application

Outline

- Background & Motivation
- The National TCAD Framework
- The Information Power Grid
- **Conclusions**

Why is NAS Involved in NTF, IPG?

- NASA Ames is Center of Excellence for Information Technology
- Unique NAS resources allow prototyping of IPG and NTF:
  - Supercomputing and parallel computation hardware
  - Advanced numerical computation software
  - Numerical and parallel computation experts
- Functionality beyond current industry interests
  - Computational applications
  - Human-computer interface (HCI)
  - Managing large computation systems (scheduling, storage, etc.)
- Provide organizing influence (and funding)
- Important to future NASA and government missions

Summary

It is critical to expand the role of TCAD in electronics soon.

Two challenges currently prevent this:

- Difficulty of creating sophisticated TCAD tools
- Lack of sufficient, affordable compute resources

Technologies were described to overcome both challenges:

- National TCAD Framework: TCAD developers join and conquer
- Information Power Grid: TCAD users join and conquer